Real-Time Robotic Surveying for Unexplored Arctic Terrain

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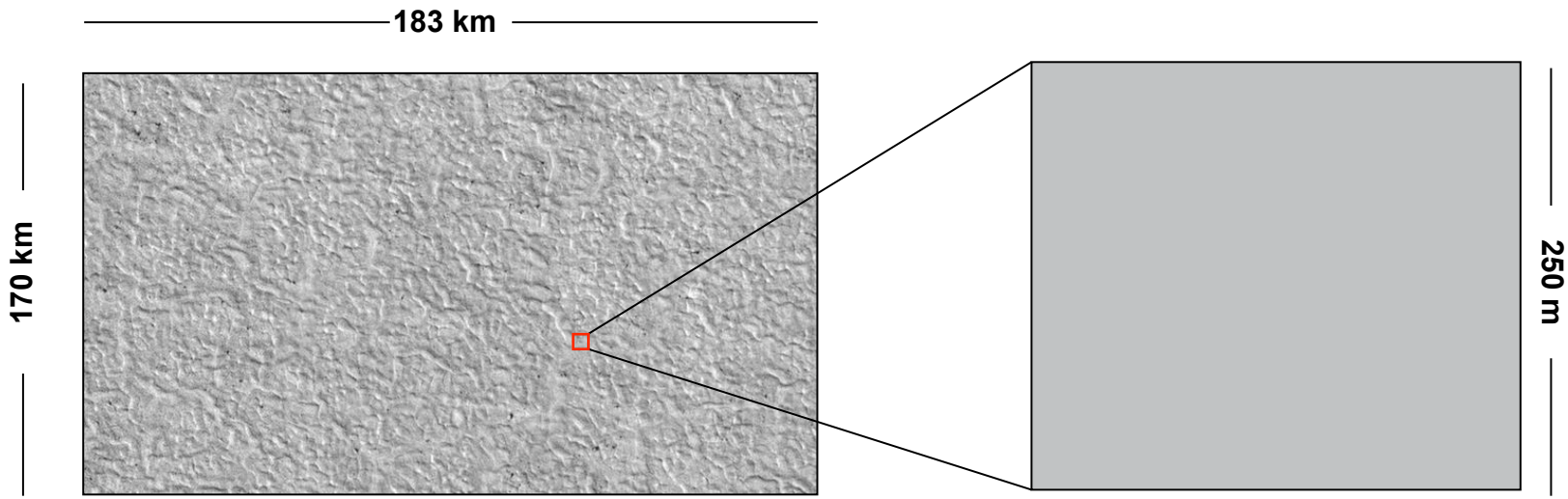
Motivation

- Objective
  - To make more information available to remote-sensing systems using autonomous or semi-autonomous robotic solutions.
  - Specifically, provide higher-resolution shape and slope characteristics of terrain than currently offered.
- Strategy
  - Intelligently collect changes in terrain using robotic technology.

Motivation

- The limitation of the pixel footprint…



*Example L7 Landsat ETM+ (Band 8) Image**

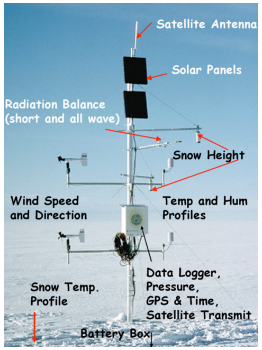
**Image acquired from Google Images*

Motivation: EOS

- An Earth Observing System needs:
  - Satellite capable of orbiting the earth
  - Multiband, high-powered radiometer (spectroradiometer)
  - Complex signal processing algorithms for imaging
- Available resources:
  - Multiple scene perspectives
    - Globally (*ex situ*): Landsat, ICESat, MODIS
    - Locally (*in situ*): Automatic Weather Stations (AWS), human field campaigns, aerial fly-bys

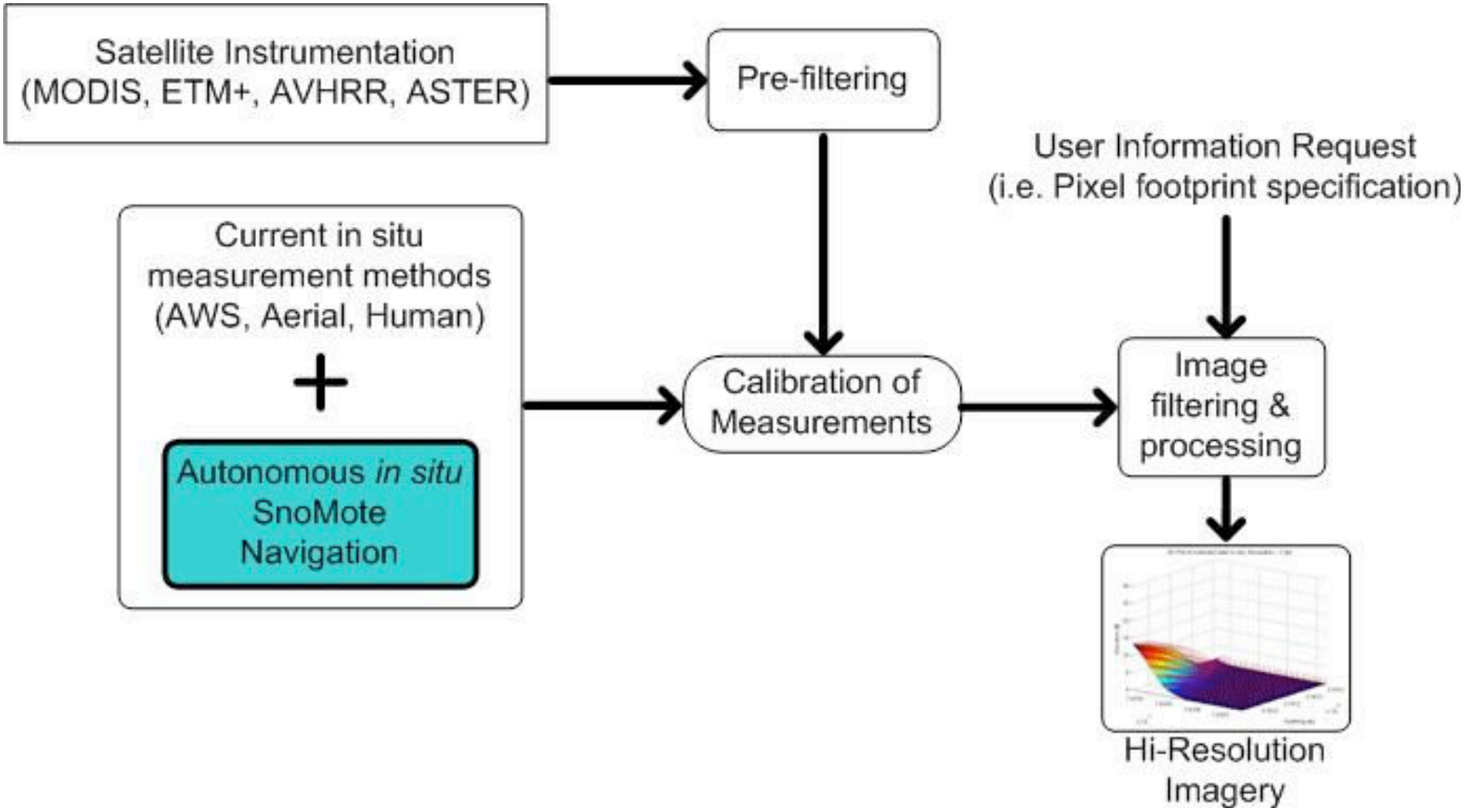
Motivation: In situ tools

- We have several options for in situ data collection.
  - Automatic Weather Stations
    - Coverage
  - Aerial campaigns
    - Cost
  - Human field campaigns
    - Safety
- Robotic alternative
  - **Mobile**
  - **Cheap**
  - **Expendable**



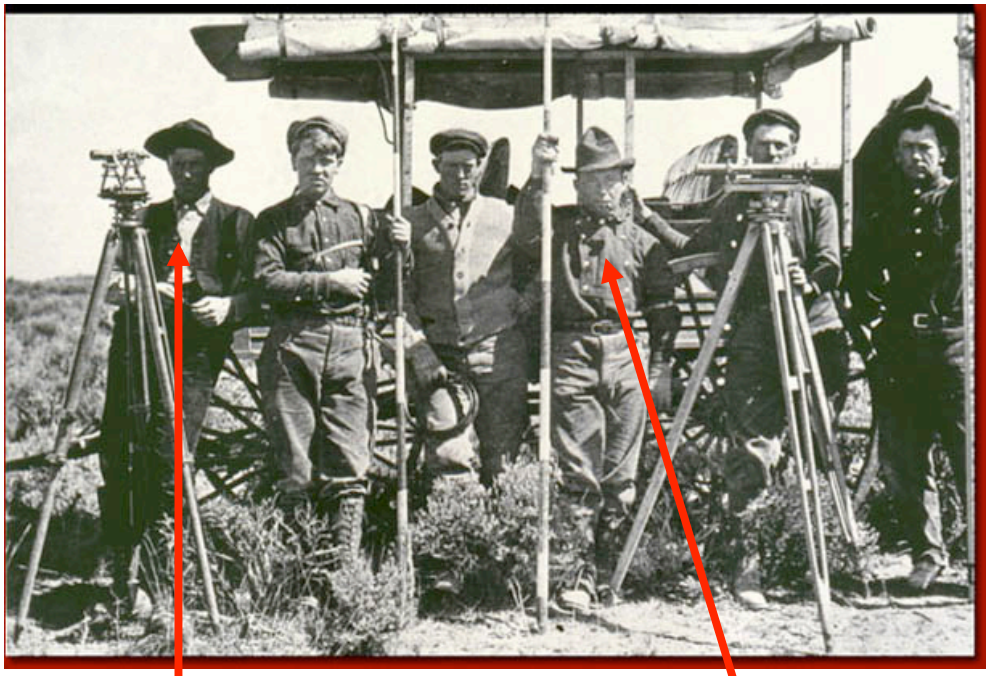
**Images acquired from Google Images*

Motivation: Augmentation



Surveying: History

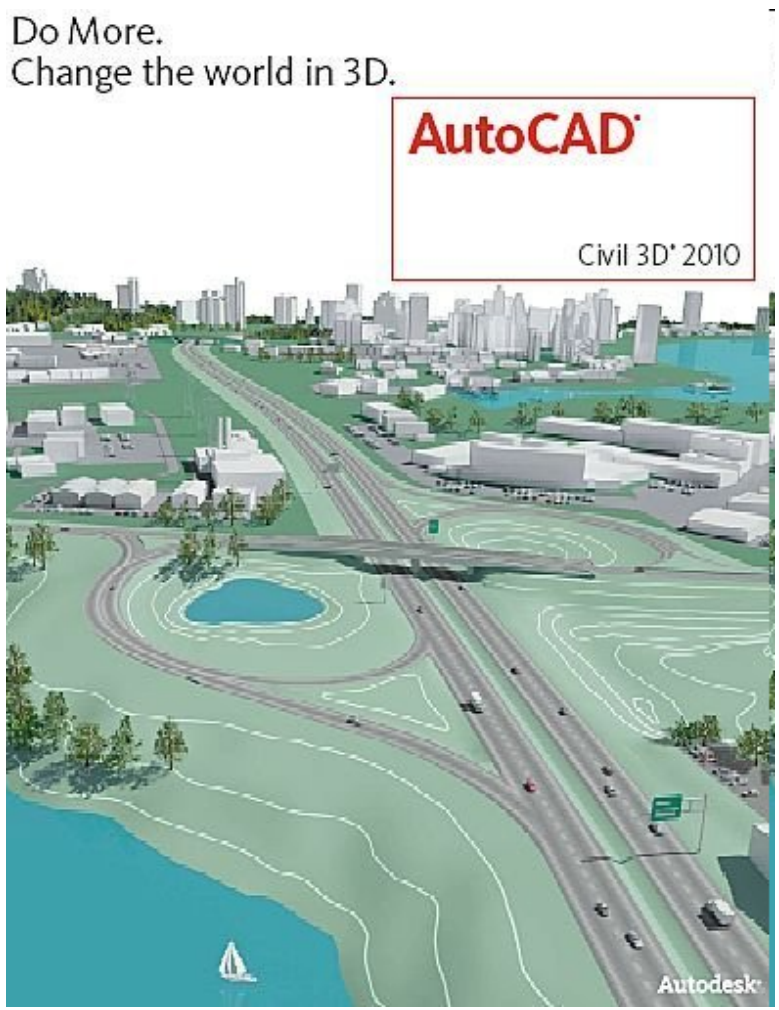
- Multitude of survey types
  - Land, Route, City/Municipal, ***topographic***, construction, hydrographic, mining, forestry…
  - Topographic surveys "are made for locating objects & measuring the relief, roughness, or three-dimensional variations of the Earth's surface." (Surveying, 2nd ed., J. C. McCormac)
- Traditional requirements
  - 2 – 3 person team: Observer, Rodman, Eyeman (optional)
  - Distance measuring equipment (i.e. EDM, GPS, tape measure, levels, leveling rod)
  - Multiple elevation measurements



Images acquired from Google Images

Surveying: Currently

- Few explicit limitations exist, but there is a balance between equipment and man power.
- Total Stations cost between $7K and $40k depending on available features and age.
- AutoCAD (w/ Civil3D package), and Land Development are used to generate contour maps based on imported data from surveyors.



Images acquired from Google Images

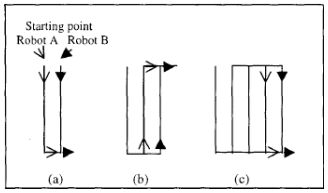
Surveying

- Defining in's and out's of surveying
  - Contacted surveyor companies to interview about modern surveying methods
    - Boundary Zone Inc.
  - Key issues: ***Measurement location selection*** and *curvature*
  - **Control Point** Vs **Checkerboard** Method
  - Curvature is defined via estimating contours
    - Less control points ←→ Less information available
  - **More information is better**…even if the customer (i.e. scientist) doesn't realize it…

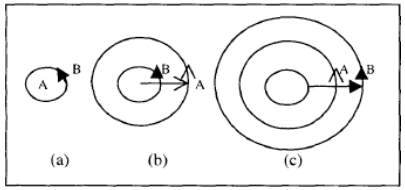
Surveying: Robotics

- Additional theoretical work was done by others including R. R. Hashemi (*U. Arkansas*) and E. Tunstel (*APL, Johns Hopkins U.*)
- Originally developed ideas for locating items in a 2D search space (i.e. water, Martian gases, etc.)
  - Focus on maximizing Quality of Performance, QoP = (A_s / D_s)

Single Agent

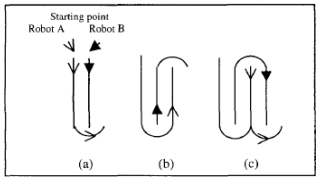


Strip Approach

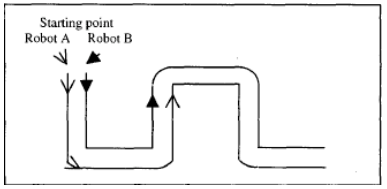


Tube Approach

Dual Agent



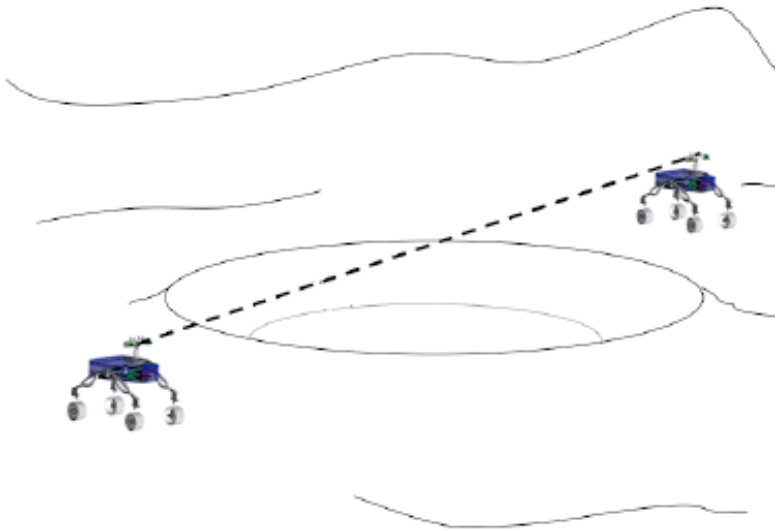
Improved Strip Approach

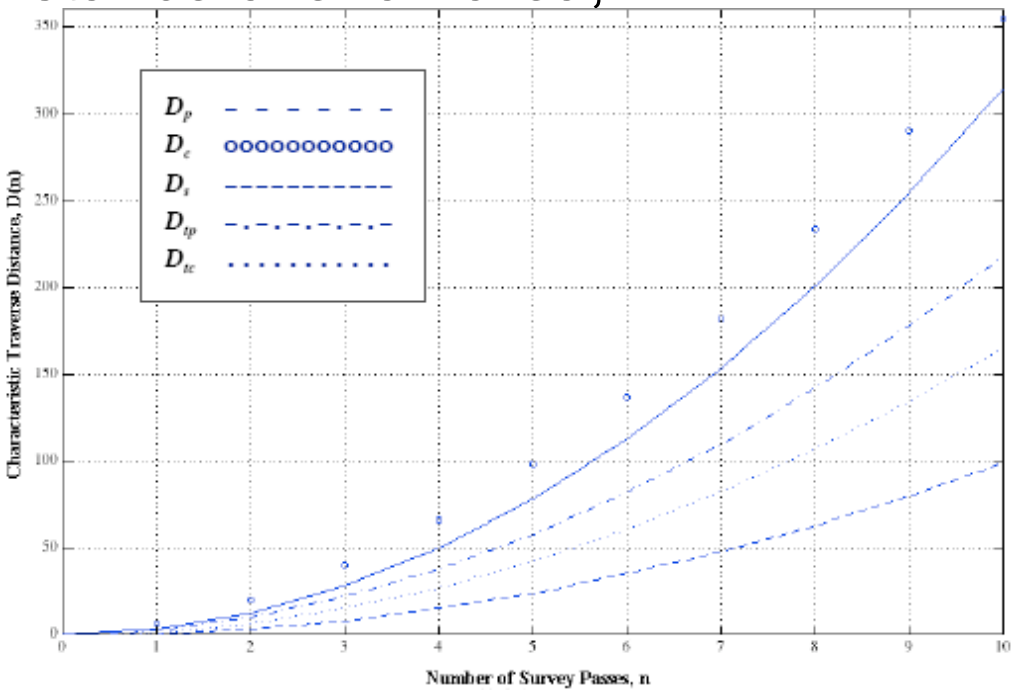


Relaxed Improved Strip Approach

Surveying: Robotics

- Emphasis of previous work is on which navigation pattern minimizes distance over an area, A.





Here, a single-agent executing a "lawnmower" pattern achieves the highest QoP, yet these patterns can be adjusted to suit the application

Image acquired from Tunstel, et al., Rover Prototype for Mobile Surveying Technology Development, NSBE ASC 2010

Surveying: Robotics

- Previous work has included applications for…
  - Pseudo-Martian planetary exploration (via simulated environments)
  - Agricultural and farming products

Autonomous Crop Treatment Vehicle (Tillett and Hague Technology Ltd)

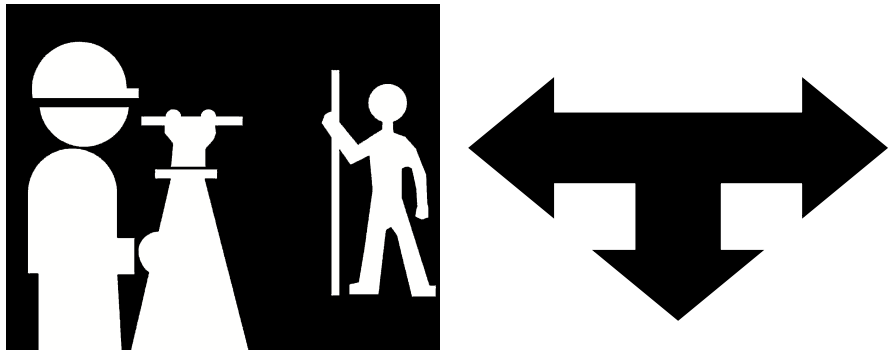
K10 Planetary Rovers (NASA)

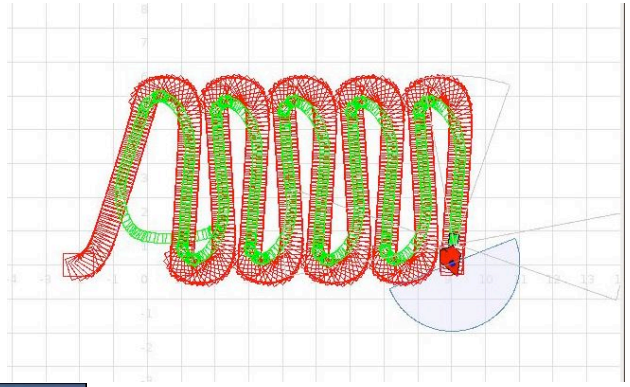
- While useful, their mission objectives varied, none of which included terrain characterization.

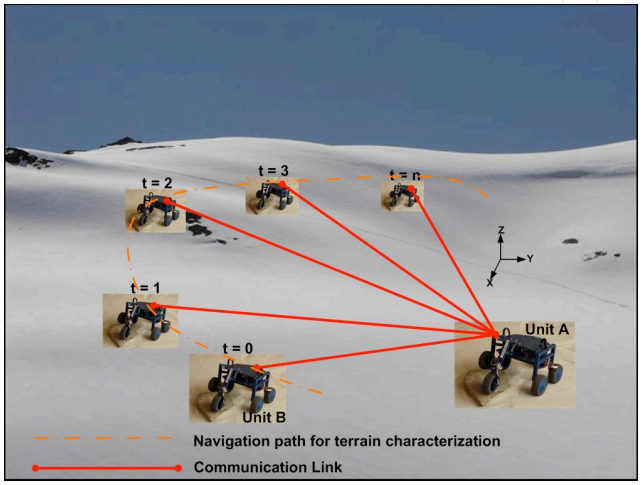
**Images acquired from http://lunarscience.nasa.gov/roboticrecon/robotic-tech/k10-robot-fast-facts AND http://www.unibots.com/Agricultural_Robotics_Portal.htm*

Approach

- Combine **land surveying principles** and **coverage algorithms** to create a robotic survey system.







Images acquired from Google Images

June 22nd, 2010

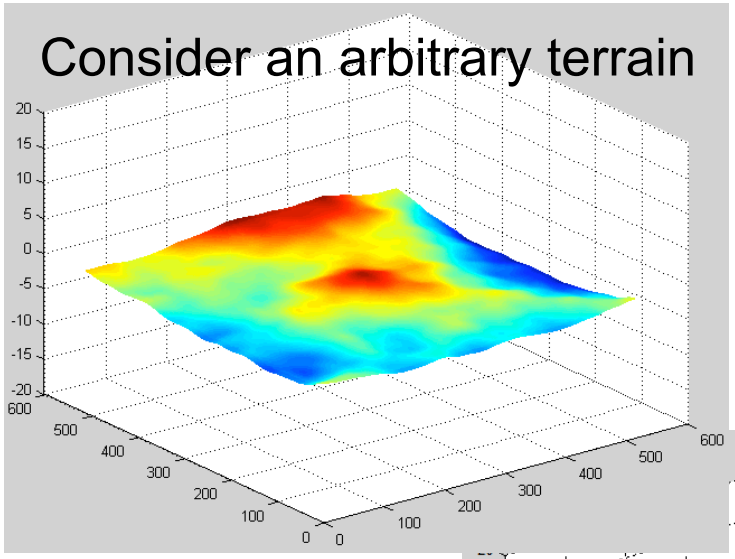
2010 NASA ESTF

Approach

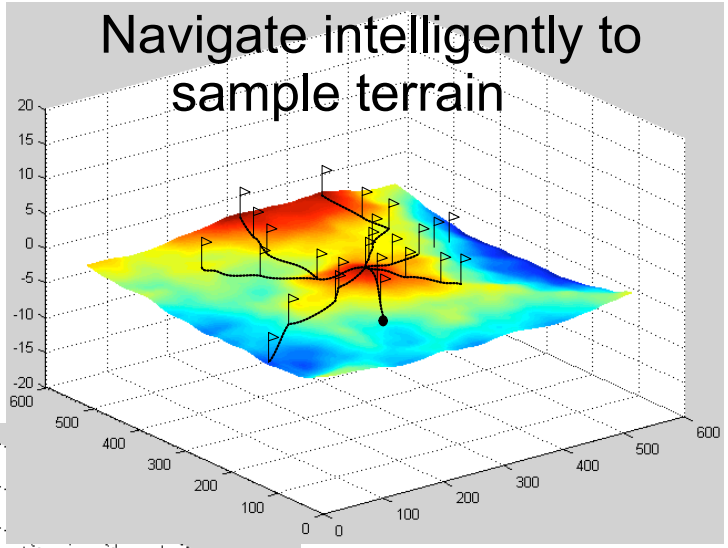
- **Claim: If surveyors base control point selection on changes in terrain elevation, robots should do the same, but do so more intelligently.**
- Presume we know…
  - A measurement of the maximum height and minimum depth of a terrain.
  - We only survey areas exhibiting a range of angular orientations.
    - $\theta_{min} < \text{Pitch}_{Terrain} < \theta_{max}$
    - $\varphi_{min} < \text{Roll}_{Terrain} < \varphi_{max}$
  - GPS is available so as to assign sensed information with a sufficiently known location.
- Problems that this research can address:
  - Obtaining a more accurate measurement of curvature.
  - Developing a specific approach to increase information gain in lieu of manually increasing the number of measurements.

Approach

Consider an arbitrary terrain

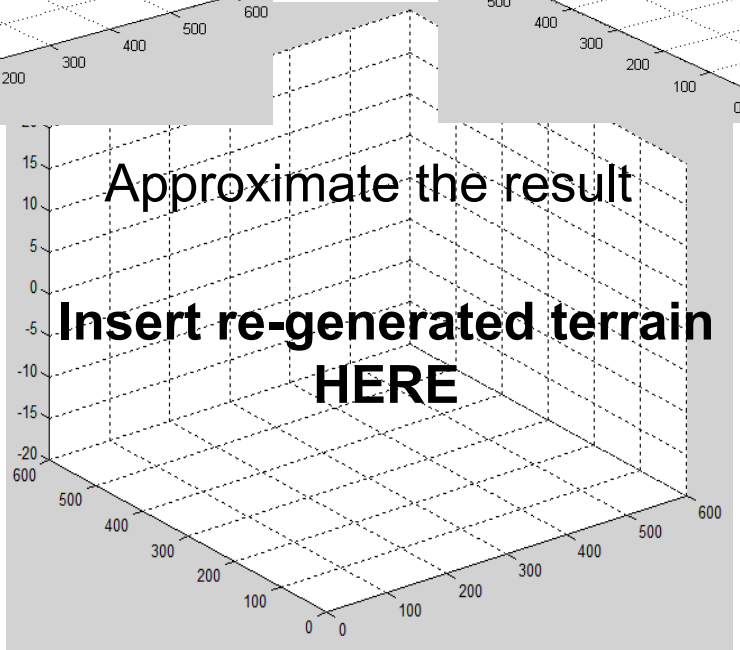


Navigate intelligently to sample terrain



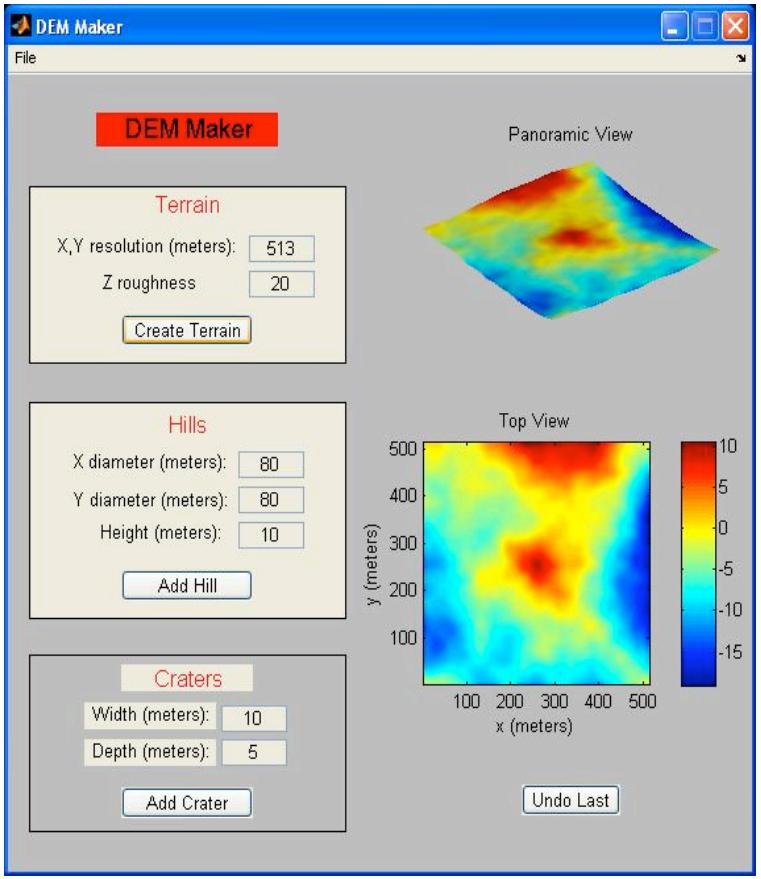
Approximate the result

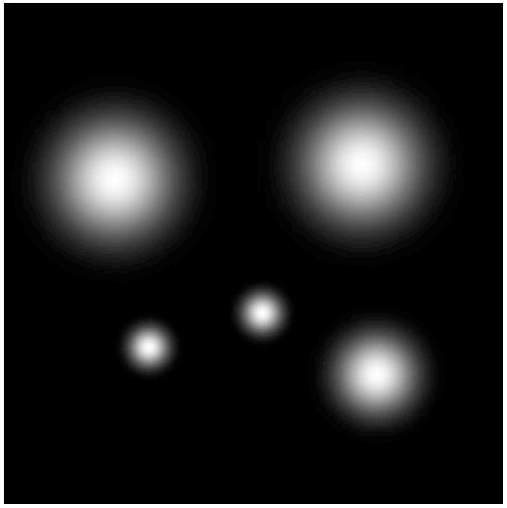
Insert re-generated terrain HERE

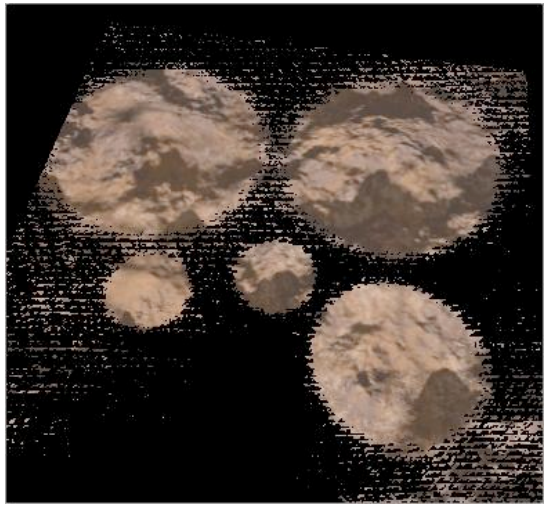


Approach

- DemMaker in MATLAB
  - Useful for simulating desired “pixel” size (~250x250 m^2 areas).
  - Both “roughness” as well as specific terrain aberrations can be simulated (i.e. hills or craters).
  - Maps are easily imported into 3D Gazebo world environment.







Approach

- Computer graphics
  - Physics-based approach to surface reconstruction using multiple finite element methods.

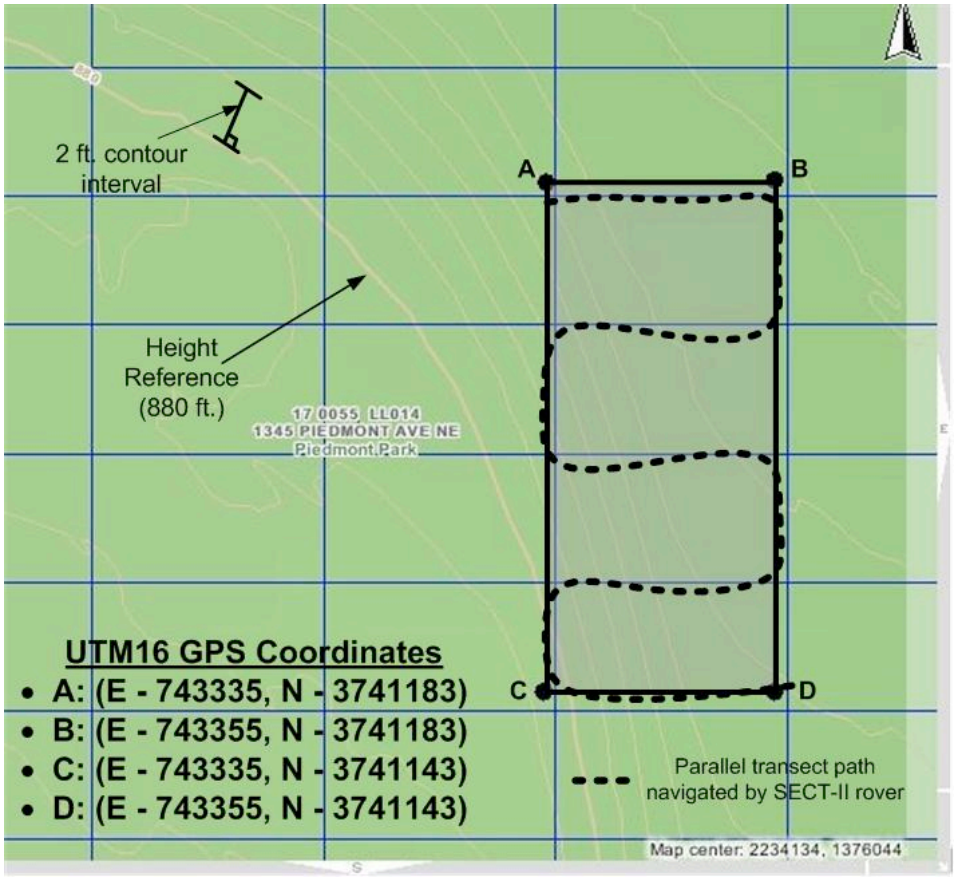
(a) (b) (c)

Figure 5: (a) Original digital terrain map. (b) Rendered contour data. (c) Reconstructed terrain.

Images acquired from http://www.scs.ryerson.ca/~tmcinern/

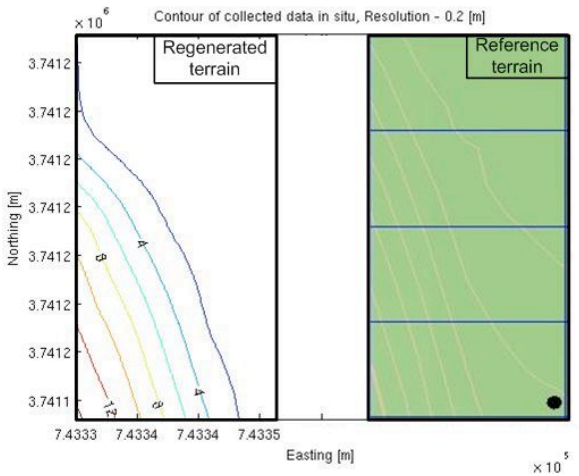
Example Application

- Field tests in Piedmont Park, Atlanta, GA
- Area Under Test was selected
  - 20 [m] x 40 [m]
  - Low undulating terrain
  - Obstacle-free
  - Elevation reference of 880 [ft]
  - Steadily increasing slope

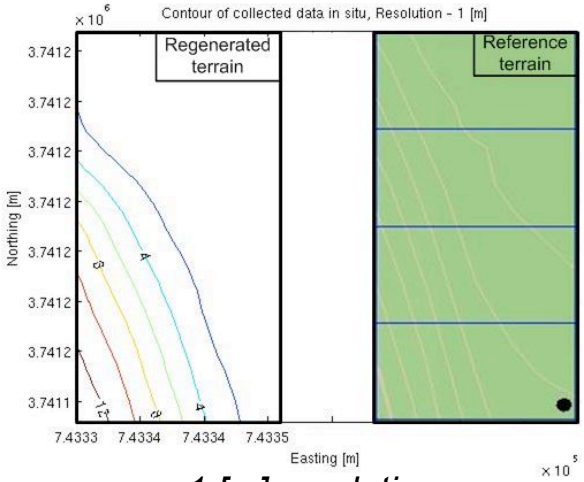


Example Application

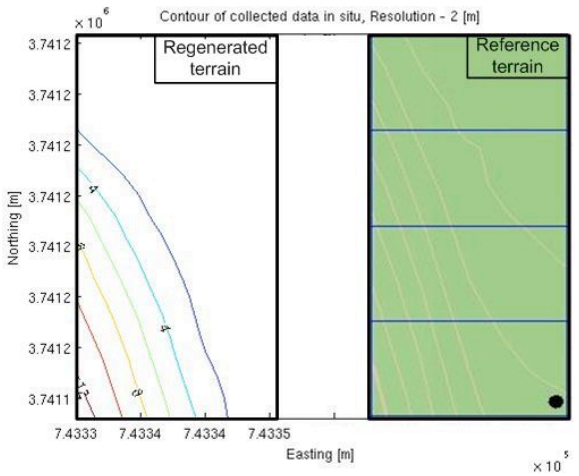
- 2D contour comparison
  - Taking contours of the regenerated data, then visually compared to the online map data shows a close comparison of 12-14 [ft] in elevation differential from the reference.
- Results presented at AIAA Infotech@Aerospace 2010, Atlanta, GA.



0.2 [m] resolution



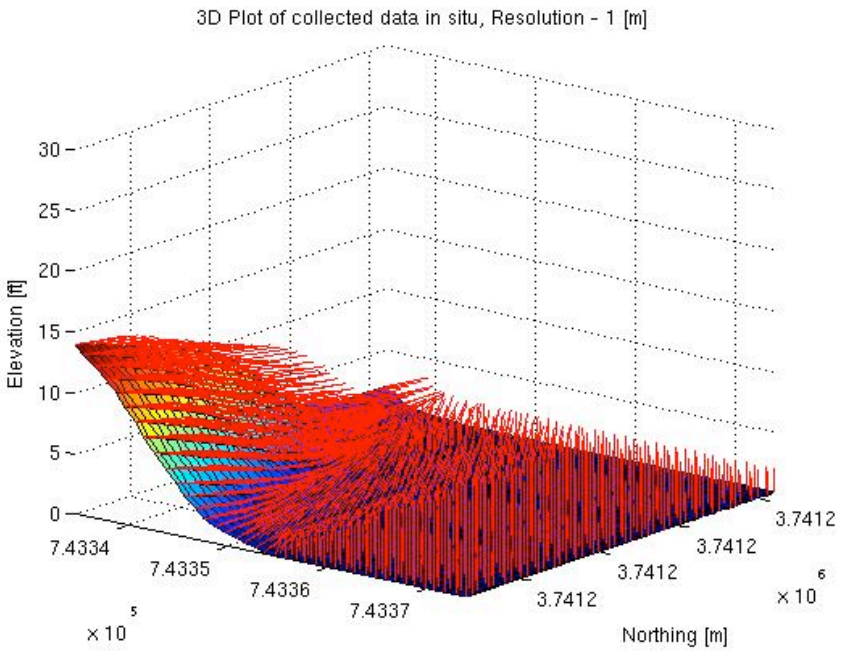
1 [m] resolution

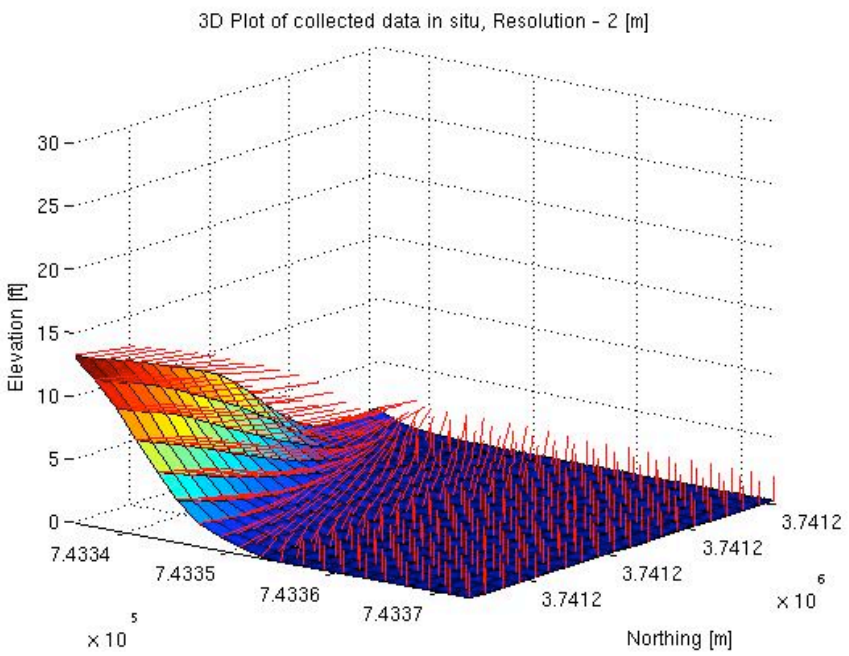


2 [m] resolution

Example Application

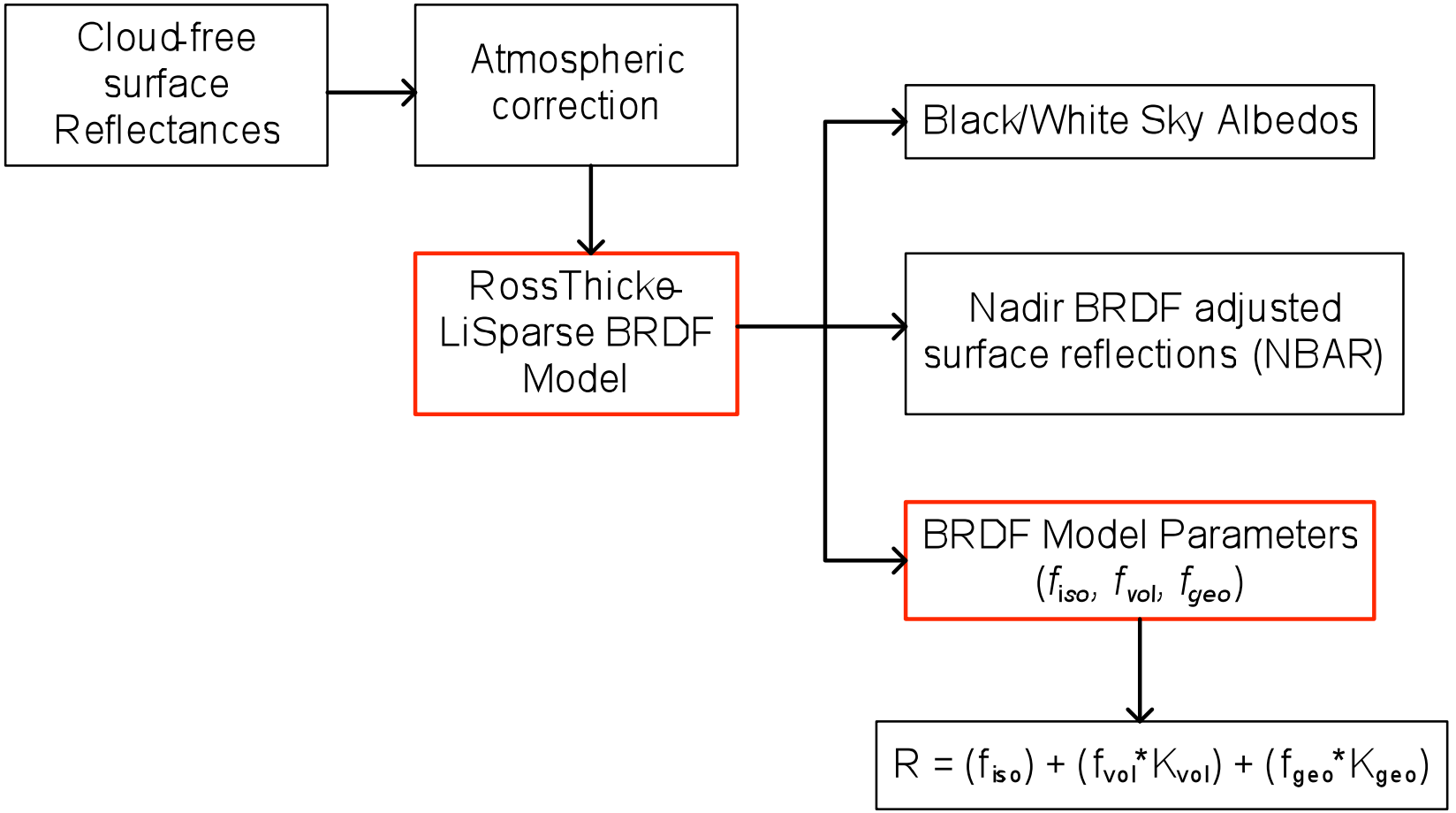
- 3D Terrain Regeneration
  - Following filtering and post-processing, we recreated the AUT at 1[m] and 2[m] resolutions.





Example Application

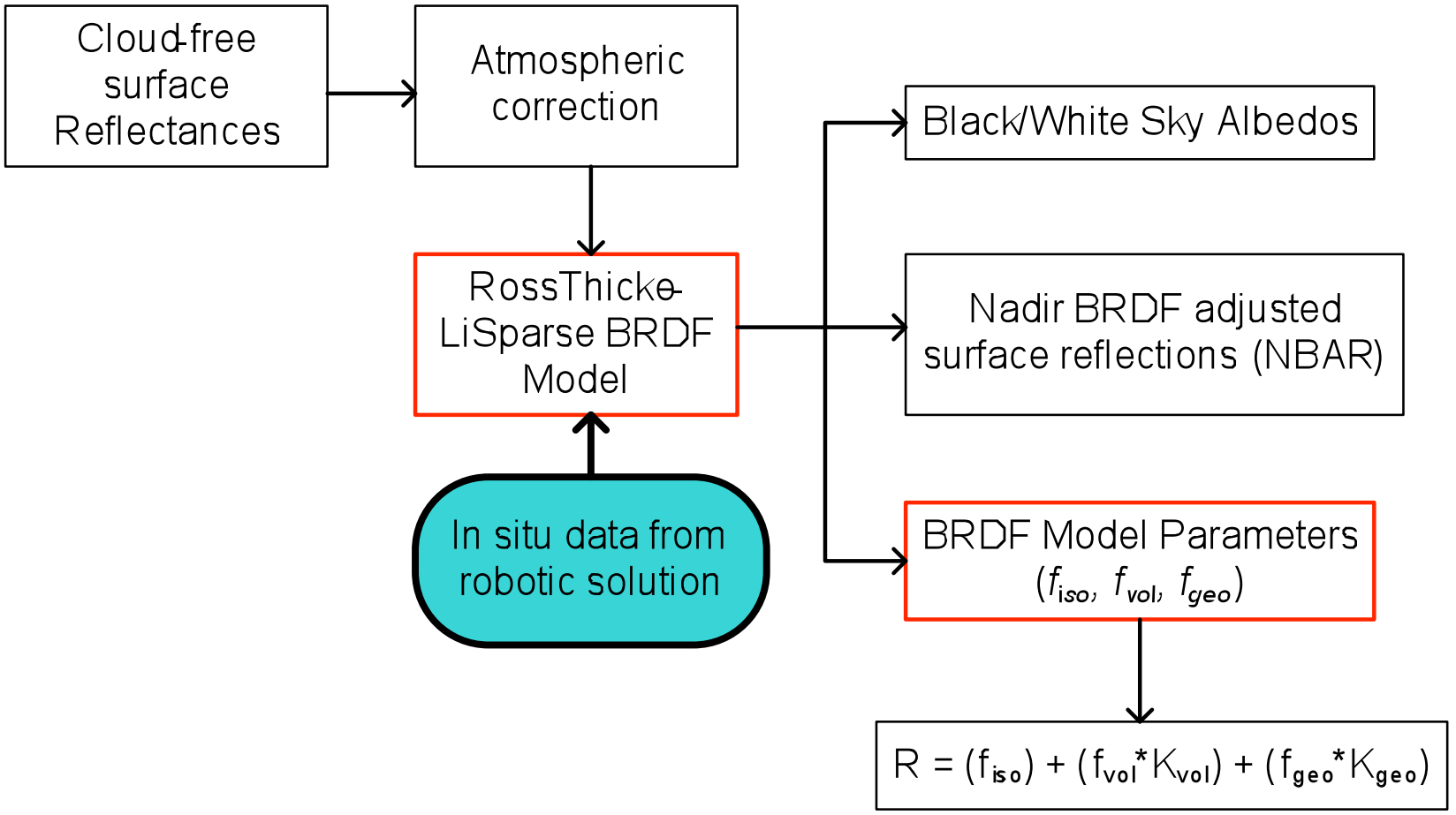
- Albedo measurement…



Courtesy of Crystal Schaaf (http://www-modis.bu.edu/brdf/userguide/intro.html)

Example Application

- Albedo measurement…

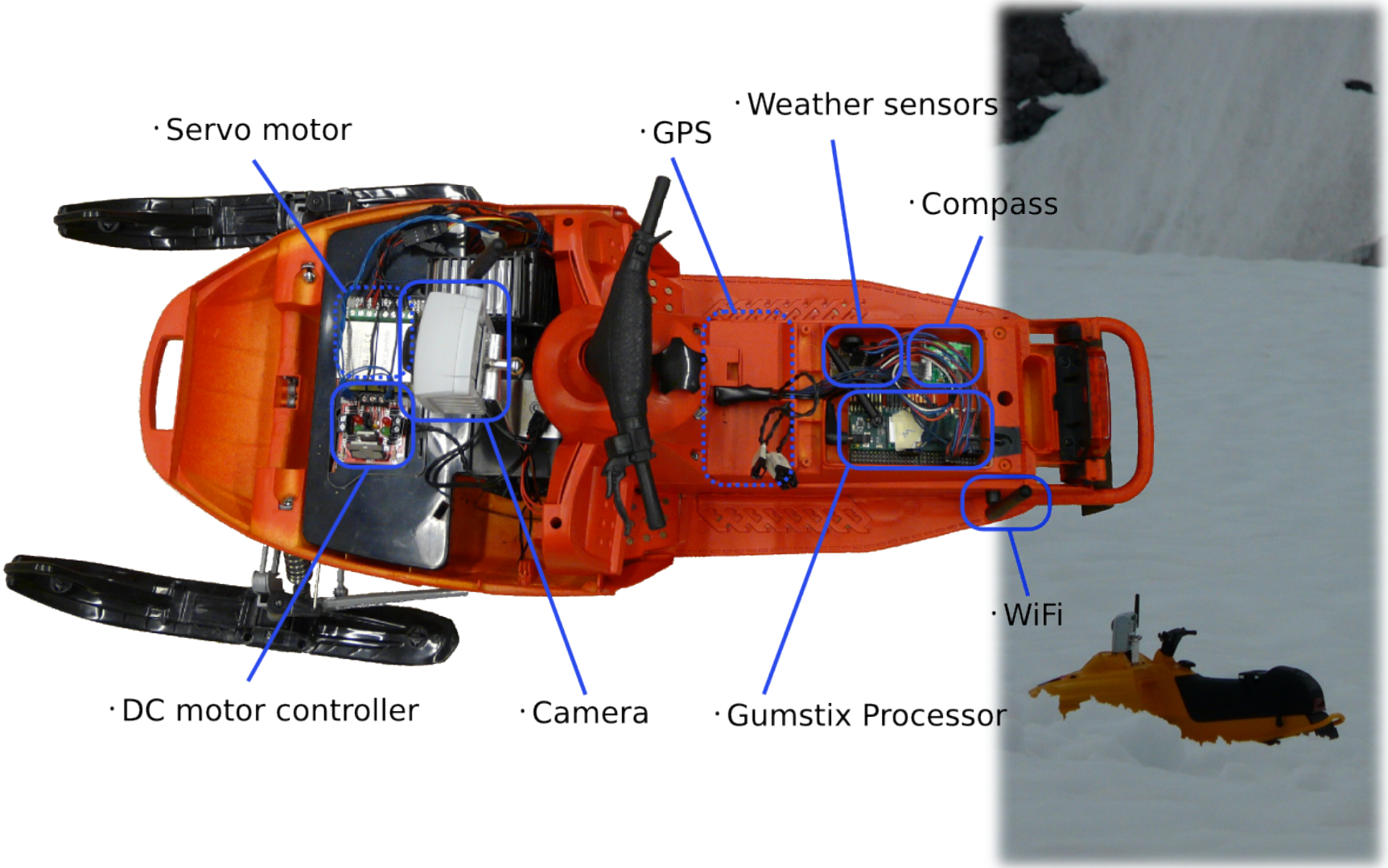


Courtesy of Crystal Schaaf (http://www-modis.bu.edu/brdf/userguide/intro.html)

SnoMote Project

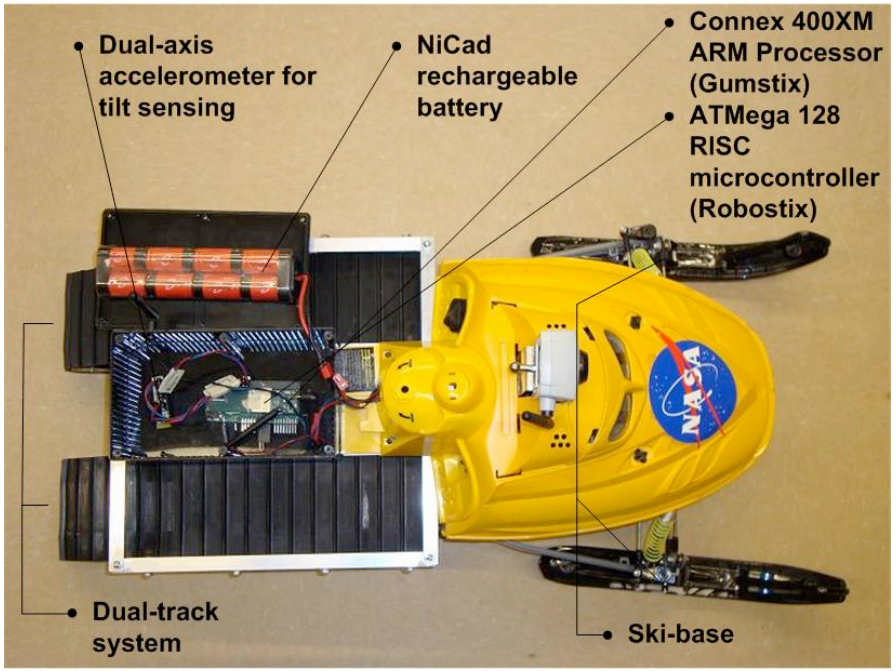
- Previous arctic robotics projects involve developing a single large expensive robot.
  - CoolRobot (Dartmouth)
  - Nomad (CMU)
  - MARVIN (U. of Kansas)
- Multi-agent systems require the development of potentially dozens of agents.
  - Inexpensive design
  - Consumer-grade sensing
  - Agent loss is tolerated
- Agents must still have significant terrain traversing capabilities.

SnoMote Project



SnoMote Project

- The SnoMotes
  - Inspired by a snowmobile design.
  - Includes on-board sensors (vision, humidity, temperature, pressure, and **tilt**) and real-time processing.
  - Field-tested in Juneau, AK on Mendenhall and Lemon Creek glaciers in June 2009.



Observations: Decadal Survey

- Relevant projects
  - Deformation, Ecosystem Structure, and Dynamics of Ice (**DESDynI**)
    - To record the response of ice sheets to climate change.
  - Gravity Recovery and Climate Experiment (**GRACE-II**)
    - Spacio-temporal fluctuations of the Earth's mass distribution.
  - Ice, Cloud, and land Elevation Satellite (**ICESat-II**)
    - Altimetry measurements to determine the contribution of terrestrial ice cover to global sea levels.
- All benefit from increased bandwidth of information afforded by robotic technology.

Observations

- Aim
  - Not to replace current capabilities, but to augment them.
  - Increase knowledge base of scientific information currently available.
  - Improve efficiency and safety of earth scientists.

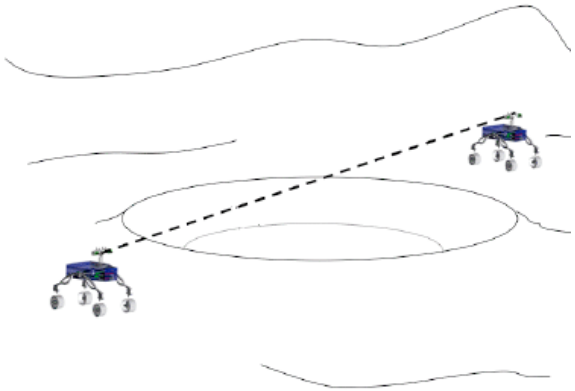


Image acquired from Tunstel, et al., Rover Prototype for Mobile Surveying Technology Development, NSBE ASC 2010

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Thank you…

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Questions?